SECTION 2.0

HYDROGEOLOGY

2.0 HYDROGEOLOGY

Hydrogeologic investigation and studies of Gregory Canyon and the surrounding area were performed to:

- provide an understanding of the water-bearing zones within the limited alluvial section and underlying bedrock,
- define the piezometeric surface and groundwater flow,
- establish existing water quality,
- establish the monitorability of the groundwater system, and
- generate an effective water quality monitoring network for the proposed landfill design.

This section provides a summary of the regional and local hydrogeology developed from geologic and hydrogeologic characterization studies completed on the site for the GCLF project.

2.1 HYDROGEOLOGIC SETTING

Gregory Canyon is located in an area dominated by crystalline rocks with intervening alluvial valleys. Limited groundwater exists in the fractures within the crystalline rocks compared with the groundwater stored in alluvial sediments. Provided herein is a discussion of the hydrogeologic characteristics in the region surrounding Gregory Canyon.

2.1.1 Regional Hydrogeologic Setting

The Gregory Canyon watershed is tributary to the San Luis Rey River and is part of the San Luis Rey Hydrologic Unit (Figure 2-1). This hydrologic unit encompasses a semi-rectangular area of about 565 square miles. The San Luis Rey River occupies a narrow valley in the basin that is filled with water-bearing alluvial sediments bounded by sedimentary rocks in the lower reach of the basin, and igneous and metamorphic rocks in the middle and upper reaches. The alluvial deposits along the San Luis Rey River form narrow elongated groundwater basins. The San Luis Rey Hydrologic Unit has been subdivided into three hydrologic areas from east to west, which include the Warner, Monserate and Lower San Luis (Mission). The Monserate Hydrologic Area occupies approximately the middle one-third of the San Luis Rey Hydrologic Unit and is the closest to the proposed landfill. The Monserate Hydrologic Area is further subdivided into three hydrologic subareas which include from east to west, the La Jolla Amago, Pauma and Pala Hydrologic Subareas (RWQCB 1994). In this area of the site, groundwater moves from east to west, down gradient from the Pauma Basin to the Pala Basin and then to the Bonsall Basin of the Lower San Luis Hydrologic Area. The boundaries of each basin are drawn where the basement complex (hard crystalline rock) is exposed at the surface and where distinct bedrock constrictions in the San Luis Rey Valley segment the valley fill. The alluvial and colluvial deposits of the San Luis Rey River and tributary canyons, are composed mainly of coarse granular materials overlying variably weathered bedrock.

Because groundwater recharge is seasonal and inconsistent, groundwater levels in the valley fluctuate. Historical depth-to-water measurements from the period between 1965 to 1990 for the alluvial aquifer indicate depth to groundwater ranges from the ground surface to approximately 25 feet below ground surface (bgs) [California Department of Water Resources (CDWR) 1971; U.S. Geological Survey (USGS) 1990].

The GCLF site is located to the south and adjacent to the Pala Basin boundary (Figure 2-2). The Pala Basin covers approximately 4,500 acres, being nearly eight miles long and averaging about 0.5 miles in width (NBS Lowry, 1995). Total thickness of the alluvial sediments in the Pala Basin ranges from zero at the basin margins to in excess of 165 feet, over the proposed GCLF bridge crossing (GLA, 2000). A study by the USGS (Moreland, 1974) estimated the maximum depth of the alluvium in the Pala Basin at 244 feet (in one well 9S/2W-26G1 located in the far upper reach of the Pala Basin), and an average depth of 150 feet. At well GMW-2 (Figure 2-3), located near the southern edge of the Pala Basin at the mouth of Gregory Canyon, the thickness of alluvium is only about 50 feet (G&M 1990).

Due to an abundance of coarse sand and gravel deposits and minimal clay, the best recharge areas are located in the central and west-central portions of the basin (NBS Lowry, 1995). Reported well yields for alluvium in the Pala Basin from a study by NBS Lowry (1995) indicate rates of production range from 300 gpm to 1600 gpm. Specific capacities for alluvium along the axis of the basin range from 13 gallons per minute per foot (gpm/ft) to greater than 115 gpm/ft of drawdown (Moreland 1974). Hydraulic conductivities range from 750 gpd/ft^2 to 1000 gpd/ft^2.

Granitic and metamorphic crystalline rocks underlie the valley fill and adjacent slopes. Groundwater occurrence and movement in the bedrock medium depends upon fracture size, frequency density and interconnection, rather than matrix properties as in alluvial soils. Though it is common usage to speak of a bedrock "aquifer" (as distinct from the alluvial aquifer), wells penetrating fractures containing groundwater are not typically a dependable source of water for large-scale agricultural, municipal or industrial uses. Highly productive wells completed in bedrock are generally those located within alluvial valleys, which store groundwater that is in hydraulic connection with the underlying fracture system (San Diego County Water Authority [SDCWA], 1997). Wells within valleys and canyons where surficial deposits are absent or minimal generally yield only small quantities of groundwater and here the bedrock aquifer may be more important for recharge to downstream alluvial aquifers.

The distinction, in terms of well yields, between alluvial and bedrock aquifers is illustrated in the histograms shown on Figure 2-4. The histograms are developed from well data presented in Table 2-1 and portray frequency of occurrence verses well yield from wells in the vicinity of Gregory Canyon. Well yields from alluvial wells follow a normal distribution about a mean yield of 300 gpm, whereas those from bedrock wells follow a log-normal distribution with a mode between 5 and 20 gpm. These results are proportional to the relative porosity of the two media (25-50% for alluvium, and 0-10% for fractured crystalline rock). The statistical distributions provide an empirical context for distinguishing between the two types of groundwater occurrence.

Although it is a source of recharge to the alluvial aquifer, there has been little attempt to quantify the properties of the bedrock flow system regionally. In fact, the Pala Basin as defined by the CDWR (1971) does not include the adjacent bedrock aquifer. The study of Lee Valley (located in the southern portion of San Diego County) by Kaehler and Hsieh (1994) is the only known comprehensive investigation of a local bedrock aquifer. It is pertinent to Gregory Canyon because of the similarity in the magnitude and distribution of bedrock well yields obtained from Lee Valley, which are included on Figure 2-4.

2.1.2 Surrounding Water Uses

Existing Groundwater Wells. Traditionally Pala Basin groundwater has been used for agricultural and livestock purposes, although more recently a few commercial materials companies have been established in the basin. The basin groundwater provides nearly all of the potable water supply for the Pala Indian Reservation, the San Luis Rey Municipal Water District (SLRMWD), and for other municipal and agricultural purposes in the basin (NBS Lowry, 1995). It is anticipated that in the future the Pala Basin groundwater within a mile of the site will be used for municipal and agricultural purposes. The USEPA has not designated the Pala Basin as a sole source aquifer.

The locations of known off-site wells within about one mile of Gregory Canyon are shown on Figure 2-2. To develop this map, water well Drillers Reports were obtained from the State Department of Water Resources. Table 2-1 provides a summary of the well information for these wells. Though, it should be noted that field verification was not performed as part of this well search. On this figure, the largest concentration of wells is in the alluvial basin of the San Luis Rey River, with a few additional domestic wells serving dwellings in Couser Canyon. It should also be noted that according to the operators of orchards south of Gregory Canyon interviewed as part of an earlier well reconnaissance, irrigation water for these orchards is derived from the First San Diego Aqueduct and not from wells.

Beneficial Uses. The Porter-Cologne Water Quality Control Act and the Federal Water Pollution Control Act Amendments of 1972 require that Water Quality Control Plans (Basin Plans) be prepared for the nine state-designated hydrologic basins in the State of California. The State Water Resources Control Board (SWRCB) approved the San Diego Region Basin Plan (Basin Plan) on March 20, 1975 and an update to the Basin Plan was drafted in 1994 (RWQCB 1994). The purpose of the San Diego Region Basin Plan is to identify beneficial water uses, establish water quality objectives, implement a program to meet these objectives, and establish a surveillance program to monitor the effectiveness of the plan.

Existing beneficial uses and water quality objectives have been established by the RWQCB for groundwater in the Pala Hydrologic Subarea to include municipal, agricultural, and industrial purposes. Because groundwater in the Pala Hydrologic Subarea is designated for use as domestic or municipal supply, chemical constituents in groundwater must not exceed the maximum contaminant levels (MCLs) as specified by both state and federal regulations. The primary standards are provided in California Code of Regulations, Title 22 (CCR 22), Chapter 15, Article 4, §64431 and 64444, Tables 64431-A and 64444-A and the Code of Federal Regulation, Title

40, part 141 (40 CFR 141). The primary standards are threshold concentrations for specific minerals and chemicals to protect human health.

The state has also developed secondary standards for constituents that may adversely affect the taste, odor or appearance of the water. These secondary MCLs are provided in the CCR 22, Chapter 15, Article 4, §64449, Tables 64449-A and -B. Groundwater in the Pala Hydrologic Subarea is also designated for use as an agricultural supply, and it should not contain concentrations of chemical constituents above these secondary standards.

Water Resources. The San Diego County Water Authority (SDCWA) is a public agency that was founded in 1944 to supplement existing supplies by importing water into the San Diego Region. In response to continued demand for water and the decreased reliability of imported water sources, recently SDCWA has been evaluating the potential to develop additional local water supplies and water storage. SDCWA is considering water conservation, water transfers, water reclamation and purification, and groundwater resource development and management. SDCWA has developed a Groundwater Resource Development Report (June 1997) to assist in developing a Groundwater Implementation Plan and to serve as a reference and resource document to be updated periodically. In this report, the Mission, Bonsall, Pala and Pauma basins within the San Luis Rey River Basin, were considered (among others) as productive shallow alluvial aquifers within the SDCWA service area.

Several SDCWA member agencies and other water agencies have either implemented groundwater projects or are planning or evaluating potential projects to develop potable water supply. Within the Lower San Luis Rey River Hydrologic Area, the City of Oceanside is extracting 2,200 acre-feet per year (AFY) of groundwater from the Mission Basin and that project is being expanded to include an additional 4,900 AFY of potable water supply. A conceptual project has also been identified by the City of Oceanside to expand groundwater development in the Mission basin by an additional 15,300 AFY of supply. The Rainbow Municipal Water District is evaluating the development of 3,000 AFY of potable supply from the Bonsall basin. For the Monserate Hydrologic Area, in which Gregory Canyon is located, the Yuima Municipal Water District is pumping up to 2,700 AFY from the Pauma basin.

SDCWA assigned a high score to the Pala/Pauma Basins, along with several other groundwater basins and surface reservoirs, during its initial "Regional Screening of New Sources of Water." Accordingly, these basins were targeted for further analysis under the "Analysis of Alternatives". The resulting analysis of alternatives ranked the groundwater basins including the Pala/Pauma groundwater basins in a lower group (less attractive), and therefore they were not considered further as a viable new source of water. The primary reasons for the low ranking included very low groundwater elevations that would require extensive pumping facilities for water conveyance, relatively little emergency storage capacity, and the need for extensive infrastructure including wells and connecting pipelines throughout the basin.

2.2 SITE HYDROGEOLOGY

As stated above, the area surrounding the project site is mixed use, with a predominantly rural character. Agricultural uses are located on the floor of the San Luis Rey drainage. Pala Rey

Ranch is located to the west of the site, Hanson Aggregates (Hanson), a sand and gravel mining operation with a concrete batch plant, is located to the northeast, lower Rice Canyon is located to the northwest, Couser Canyon is to the south, and the Pala Indian Reservation, which includes a portion of Gregory Mountain, is located to the east. The abandoned Lucio Family Dairy, which closed in 1986, is located north of the San Luis Rey River, and south of SR 76. The abandoned Pete Verboom Dairy exists to the west of the Lucio Dairy and is adjacent to and south of SR 76.

Agricultural land refers to areas supporting active agricultural cultivation or cattle grazing. About 97 acres of agricultural land, primarily grazing areas, exist on the project site. The dairies on the project site, which are also considered agricultural lands, were mapped as a combination of agricultural land and developed land and occupy 88.3 acres. Existing land uses within the general area include a pear orchard, pastures, various farm outbuildings, and dirt access roads along fields. Pastures and a hay shed are situated on the valley floor on the south side of the river. The Hanson's sand and gravel mining operation and concrete batch plant is located approximately 1,200 feet upstream of the existing First San Diego Aqueduct crossing of the San Luis Rey River.

2.2.1 Local Hydrogeology

Gregory Mountain is an elongated, relatively flat-topped prominence, drained to the east, north and west (into Gregory Canyon) by steep, rocky secondary canyons. The potential catchment area of the mountain is large and it clearly dominates recharge to Gregory Canyon. Recharge to Gregory Canyon from the west ridgeline and southern drainage divide is believed to be relatively minimal. Though no permanent springs have been identified in Gregory Canyon, the vigorous development of riparian vegetation along the thalweg of the canyon, and its tributaries, suggests that the piezometric level of the underlying aquifer is close to the surface along the lowest points of the canyon. Studies by GLA, and others including the drilling and construction of groundwater monitoring wells, have assisted in evaluating groundwater flow within the project area.

There are two distinct groundwater zones within Gregory Canyon. An alluvial aquifer hosted by the sediment wedge at the mouth of the canyon, and a bedrock aquifer hosted by the fractured tonalite that forms the substrate of the canyon. The general direction of groundwater movement in both aquifers is northerly, toward the alluvial aquifer of the San Luis Rey River (Figures 2-3A and 2-3B; Plate 2).

<u>Alluvial Aquifer.</u> An alluvial wedge occupies the lower reaches of Gregory Canyon. Figure 2-3A shows a contour map of the water table in the alluvial aquifer based on data collected on December 16, 1996 (the most recent time when significant groundwater was measured in the on-site alluvial wells). It pinches out to the south (as indicated by dry wells MW-4, WCC-1, WCC-2, and MW-5) before reaching the proposed landfill footprint. WCC (1995) concluded that groundwater within the alluvium forms an unconfined aquifer recharged by direct infiltration from precipitation or runoff from the bedrock ridges east and west of the canyon, and by underflow through weathered bedrock. The available data suggest groundwater flow is to the north, under a gradient of about 0.045 ft/ft.

As stated above, the reported hydraulic conductivities for alluvium in the Pala Basin range from 750 to 1,000 gpd/ft^2 (Moreland 1974). In contrast to the more coarse-grained sediment typical of the Pala Basin as a whole, WCC (1995) estimated that the hydraulic conductivity of alluvial and colluvial materials in Gregory Canyon ranges between 0.9 and 16 gpd/ft^2. Supporting this lower local value, Geraghty & Miller (1990) performed a pumping test in well GMW-3 and estimated the transmissivity of the alluvial aquifer using the Cooper-Jacob method, at 700 gpd/ft, and from this value the hydraulic conductivity was estimated to be approximately 1.47 ft/day (11 gpd/ft^2).

Bedrock Aquifer. There are 19 bedrock monitoring wells within the proposed landfill footprint and along the periphery of the site, constructed during various investigative phases of the project (Figure 2-3B). Studies conducted to date indicate that groundwater in Gregory Canyon can be characterized as a fracture-controlled, interconnected flow system. This fracture-controlled groundwater communicates with, and recharges the alluvial water in the San Luis Rey River valley (Pala Basin). The fractured bedrock flow system can be differentiated into an upper zone of active flow through a network of interconnected fractures and weathered rock, and a deeper zone of relatively low flow through more widely spaced fractures. Boreholes drilled within the canyon itself encountered tonalite with various degrees of hydrothermal alteration, and significant fracturing in the upper 50 to 100 feet. Water-bearing fractures become sparse at depths greater than 100 feet. A synopsis of the results of studies performed by GLA supporting these conclusions is provided below.

Wells accessing the water-bearing fractures register water levels defining a systematic piezometric surface (Figure 2-3B; Plate 2). The piezometric surface reflects the main elements of the topography and illustrates the role of Gregory Mountain as the principal recharge area of Gregory Canyon. Derivation of a piezometric surface from wells isolated from one another by non-water bearing rock attests to the hydraulic interconnection of the fracture system.

2.2.2 Hydrophysical Logging Results

As shown on Plate 2, site groundwater investigation wells include thirteen wells and piezometers installed into alluvium and/or bedrock by previous consultants, an initial nine bedrock borings drilled by GLA (GLA-1 through -5 and GLA-7 through -10; proposed well GLA-6 was found to be an undrillable location), and an additional six alluvial and/or bedrock groundwater monitoring wells to further characterize the site and supplement the proposed groundwater monitoring system. The initial nine GLA borehole locations were selected based on geophysical very low frequency (VLF) anomalies, inferred structural lineaments, prominent geologic or topographic features (GLA, 1997).

Borehole Imaging. Wells that were completed in the crystalline bedrock were completed with an open hole (no filter pack or imported screen) allowing the well to be tested using various geophysical tools. A total of 14 of these boreholes were logged with an optical borehole imaging probe (BIP) by COLOG, Inc of Golden, Colorado. This technique is based on direct optical observation of the wall of the borehole and is recorded on videotape for viewing. Based on inspection of the BIP log each fracture is identified with a depth, orientation, and fracture ranking from 0 to 5, with a 0 indicating a closed feature, and 5 indicating a wide aperture fracture or fracture zone. Most of the fractures rank from 0 to 2, with only 20 cracks ranked at 3 and only two fractures ranked at 4 (GLA, 1997). A well by well summary of the BIP log data is provided in the Hydrogeologic Investigation Report by GLA (1997) along with a discussion of the cumulative results of fracture strike orientation and dip angles plotted for all of the tested wells. Structural orientation and spatial distribution patterns of fractures in boreholes were consistent with the analysis of similar outcrop data (Section 1.3.2).

Despite the relative abundance of fractures observed in boreholes, few were ultimately correlated with groundwater flow (see below). As suggested by the ranking survey noted above, and by close examination of the borehole videotapes, most fractures are closed with no discernible aperture, or they are filled with mineralization. Fractures in the latter category are vein-like features with no apparent porosity. Some small igneous dikes and large mineral veins related to plutonic processes have been counted as fractures in several boreholes. These features are not water bearing, and would not change the results of the borehole survey were they accounted for. Therefore, from the surface and subsurface fracture observations, it is concluded that while fracture density is significantly high in the bedrock, generally secondary porosity in the water-bearing zone is probably very low.

<u>Borehole Dilution Testing.</u> To determine the transmissive intervals within boreholes, COLOG, Inc. (GLA, 1997) adapted the borehole dilution method, using de-ionized water as the tracer and periodic measurements of the ambient temperature and fluid electric conductivity (FEC) as measures of "concentration" of the tracer. Once borehole water has been diluted with the deionized water to reduce the FEC and create thermal equilibrium, changes in the temperature and the FEC assist in locating hydraulically transmissive zones in the bedrock, and calculating the average velocity of the groundwater moving from these zones into the open borehole. The results obtained by COLOG, Inc. after applying this technique in the logging of 11 wells are summarized below.

1. As shown in the following table, in shallow wells (e.g., GMW-1, GMW-4, and GMP-2), and in the shallow portions of wells GLA-5 and GLA-7, the transmissive intervals are broad and continuous, consistent with the deeply weathered nature of the tonalite, which for all practical purposes behaves as a silty sand.

Well	Depth to water (feet)	Depth of transmissive interval (feet)	"Saturated" interval (feet)	Percent of "saturated" interval	Specific discharge (ft/day)
GMW-1	21.89	65-83	68	NA[a]	0.26-0.31
GMW-4	65.72	66-74	50	NA[a]	0.11-0.13
GMP-2	69.54	70-86	18	NA[a]	0.14-0.18
GLA-5	42.57	43-66	147	16%	0.05
GLA-7	34.82	35-72	125	30%	0.16-0.24

Note:
a. The "saturated" section of this borehole is within heavily weathered tonalite, and is too short to allow for a meaningful percentage comparison with deeper, unweathered tonalite.

2. As shown in the following table, in the deeper portion of the GLA wells, where the tonalite is less weathered, there are very few transmissive intervals. They range in thickness between 2 and 8 feet, and represent between 1% and 5% of the total length of the bedrock section. These results are indicative of fracture flow.

Well	Depth to water (feet)	Depth of transmissive interval (feet)	"Saturated" interval (feet)	Percent of "saturated" interval	Specific discharge (ft/day)
GLA-1	37.10	ND	263	NA	ND
GLA-2	69.73	83-85	180	1.1%	0.17
GLA-3	23.84	66-70, 82-84	126	3.2%	0.23/ 0.29
GLA-4	68*	70-72, 126-134	172*	1.2%/4.7%	0.03/0.07
GLA-5	42.57	96-99	147	2.0%	0.06
GLA-8	62.40	175-180	238	2.1%	--
GLA-10	22.20	58-64	128	4.6%	0.02

Note:
* The static depth to water was 149.93 feet bgs, but the transmissivity of the well was so low that water added during testing did not drain. Thus, the reported transmissive intervals and specific discharge values are transient.

3. For the deep GLA wells, in all but one instance the intervals of groundwater flow are within 60 feet of the piezometric surface. Groundwater flow is largely concentrated in discrete shallow fracture zones. Deeper fractures possess lower transmissivity, apparently as a result of more complete mineralization.

Assuming that the porosity of the deeper intervals is 1% and that specific discharge values calculated for the deeper transmissive intervals range between 0.02 and 0.3 ft/day, the equivalent specific discharge would be between 0.0002 and 0.003 ft/day. Using an average groundwater gradient value of 0.15 ft/ft, determined from the contour map of the piezometric surface, the hydraulic conductivity would range between 0.0013 and 0.02 ft/day (4.6E-07 cm/sec to 7.1E-06 cm/sec).

Packer testing estimates of the hydraulic conductivity of the deeply weathered bedrock ranged from 0.03 to 0.3 ft/day (10^{-5} to 10^{-4} cm/sec) (Geraghty & Miller, 1990).

Cross-hole aquifer tests. COLOG, Inc. also performed three cross-hole aquifer tests to quantitatively assess the interconnectivity of the bedrock aquifer, using the following well pairs:

Pumping well	Observation well	Distance between wells	General location in the canyon
GMW-1	GLA-3	51 feet N36E	Lower reach
GMP-2	GLA-7	167 feet N56W	Middle reach
GMW-4	GLA-8	30 feet N10E	Upper reach

For cross-hole flow assessment, the formation water in the observation well is replaced with deionized water (DI) while the nearby well is pumped. As pumping continues, a series of FEC and temperature logs are then run in the observation well to identify changes in the fluid conductivity as a result of fluid flow. In effect, formation water coming into the observation well "enriches" the electric conductivity of the DI "tracer" so that inflow velocities can be estimated through the borehole dilution method discussed above.

The hydraulic connection between the pumping and observation wells is estimated by comparing the flow conditions in the observation well under ambient flow conditions (discussed above) and under cross-hole pumping conditions. By comparing the horizontal flow velocities of transmissive intervals under these two different pressure states, a qualitative evaluation of which intervals are hydraulically connected can be achieved. Using this technique, those intervals that display change in flow between the two pressure conditions can be assumed to be hydraulically connected.

For the cross-hole test in which GMW-1 was the pumping well and GLA-3 was the observation well, COLOG concluded that significant change occurred at three distinct depth intervals within GLA-3 – 48 to 56 feet, 66 to 68 feet, and 82 to 84 feet. In effect, these intervals experienced flow created by the stress imposed by pumping. The data yielded a specific discharge in the aquifer of 0.37, 0.28, and 0.50 ft/day, respectively. The interval from 48 to 56 feet had negligible horizontal flow under ambient conditions, and therefore, had the greatest change during cross-hole pumping conditions. The interval of 66 to 68 feet experienced an increase of 22% with respect to the ambient flow condition. Finally, the interval from 82 to 84 feet experienced a 72% increase in the average flow velocity with respect to the ambient flow condition. For this well pair, then, the "capture radius" extends at least 51 feet in the horizontal direction and 60 feet vertically into the aquifer (i.e., the distance between the depth of the piezometric surface [24 feet] and the depth of the 82-84 feet transmissive interval).

For the cross-hole test in which GMP-2 was the pumping well and GLA-7 was the observation well, COLOG concluded that significant change occurred at numerous zones over the interval from 34 to 91 feet. To discretize the specific intervals for horizontal flow analysis, the results of the ambient and cross-hole tests were evaluated in the following discrete intervals between 33 and 94 feet: 33-42 feet, 42-48 feet, 48-52 feet, 52-58 feet, 58-62 feet, 62-69 feet, 69-72 feet, 72-76 feet, 76-79 feet, 79-88 feet, and 88-94 feet. The resulting data yielded specific discharges in the aquifer of 0.24 to 0.42 ft/day. The intervals between 33 and 62 feet experienced increases in horizontal flow velocity of 13% to 79%, while the intervals at 62 to 69 and 69 to 72 feet displayed a 102% and 146% increase, respectively. The intervals between 72 and 94 feet did not display observable horizontal flow under ambient flow conditions, but were "opened" by the stress imposed by pumping. In summary, the data suggest that the intervals from 33 to 72 feet in well GLA-7 have a significant hydraulic connection to pumping well GMP-2. For this well pair, then, the "capture radius" extends at least 167 feet in the horizontal direction and 60 feet vertically into the aquifer (i.e., the distance between the depth of the piezometric surface, 35 feet, and the lower-bound depth of the transmissive interval, 94 feet).

For the cross-hole test in which GMW-4 was the pumping well and GLA-8 was the observation well, COLOG concluded that significant change occurred at numerous zones over the interval from 70 to 90 feet, and at a discrete interval at a depth of 178 to 182 feet. The results of the cross-hole test for the 70 to 90 feet inflow zone were evaluated as four discrete intervals – 70-75, 75-80, 80-85, and 85-90 feet. These data yield a range in specific discharge in the aquifer from 0.27 to 0.29 ft/day (this same interval was a zone of outflow from the borehole under ambient flow conditions, so calculation of a percent increase rate in flow is not meaningful). The inflow at the 178 to 182 feet interval under cross-hole pumping conditions was 19% larger than under ambient flow conditions. These data suggest that the "capture radius" of this well pair extends at least 30 feet in the horizontal direction and 120 feet vertically into the aquifer (i.e., the distance between the depth of the piezometric surface, 62 feet, and the lower-bound depth of the lower transmissive interval, 182 feet).

As stated above, all three cross-hole tests documented hydraulic connectivity between the pumping and the observation wells. Based on the 167-foot capture radius documented by the pair GMP-2/ GLA-7, an initial assumption of monitoring wells spaced at an average spacing of 300 feet may be reasonably expected to detect potential groundwater impacts under the proposed landfill. However, additional cross-hole testing would be performed in the dedicated monitoring wells to confirm the extent of their capture zones, and the spacing between the wells reduced or extended based on the pumping test data.

2.2.3 Groundwater Pumping Tests

To further characterize the hydraulic properties of the bedrock aquifer, GLA conducted two pumping tests in November and December 2000 (GLA, 2001). The first test was performed at the toe of the canyon, pumping in well GLA-3 over a period of 27 hours at a constant rate of 10 gpm, while measuring changes in drawdown in observation wells GMW-1 (51 feet away) and GLA-13 (200 feet away). The second test was conducted further up the canyon in fractured bedrock below the zone of weathering, pumping from well GLA-8 over a period of 24 hours while observing drawdown in well GMW-4, located 21 feet away. A summary of the pumping test results is provided in Table 2-2 and the pumping test data is provided in Attachment 4.

Results from the first pumping test at well GLA-3 indicate that while pumping at 10 gallons per minute (gpm), approximately 9 feet of drawdown was observed in the pumping well GLA-3. Drawdown of nearly 5 feet and 2 feet was measured in the observation wells GMW-1 (at a distance of 51 feet) and GLA-13 (at a distance of 200 feet), respectively. As a result, it is concluded that the wells are in hydraulic communication to a distance of at least 200 feet (to GLA-13), and distance-drawdown analysis indicated an effective radius of influence of approximately 1000 feet from well GLA-3. Average hydraulic conductivities of 2.6E-03 ft/min (1.3E-03 cm/sec) and 4.6E-03 ft/min (2.3E-03 cm/sec) were calculated and used to derive transmissivity values of between 9.5E-02 ft^2/min (1023 gpd/ft) to 2.8E-01 ft^2/min (3016 gpd/ft) from the first pumping test.

Results for the second pumping test at well GLA-8 also showed that these wells are in hydraulic communication through unweathered bedrock. Hydraulic conductivities for well GLA-8 were approximately 6.8E-05 ft/min (3.1E-05 cm/sec) for earlier pumping times and 1.1E-05 ft/min (5.6E-06 cm/sec) for longer times. Similar hydraulic conductivities were calculated for well GWM-4 of 3.4E-04 ft/min (1.7E-04 cm/sec) and 2.1E-04 ft/min (1.07E-04 cm/sec), respectively. Distance-drawdown analysis indicated an effective radius of influence of 250 feet from well GLA-8 when pumping at 2 gpm. Using the calculated hydraulic conductivity values and aquifer thickness estimates, early and late transmissivity values range from 1.2E-02 ft^2/min (129 gpd/ft) to 8.7E-04 ft^2/min (9 gpd/ft).

The lower hydraulic conductivity values obtained from the second pumping test reflect testing within the unweathered, fractured bedrock compared with the first pumping test performed at the toe of the canyon where there is a thicker weathered bedrock below alluvial/colluvial portions of the aquifer that may be recharging the underlying fractured bedrock.

2.3 CONFIGURATION OF THE WATER TABLE (PIEZOMETRIC SURFACE)

Both a water table and a piezometric surface describe the occurrence of groundwater in Gregory Canyon. A piezometric surface represents the hydrostatic pressure head above any point in the subsurface. The 'dry well' shown in Figure 2-5 illustrates the case where no water-bearing fractures are encountered in the screened interval, thus no water is produced in the well, although the well access does lie below the piezometric surface. Therefore, a dry well could indicate that the piezometric level is below the bottom of the well, or it indicates that the borehole did not intersect open fractures (as identified at well GLA-9).

Figure 2-3A shows a contour map of the water table in the alluvial aquifer based on data collected on 12/16/96. This aquifer likely merges with the San Luis Rey alluvial aquifer to the north. Groundwater flow is to the north, under a gradient of about 0.045 ft/ft. Figure 2-3B and Plate 2 present a contour map of the piezometric surface in the bedrock aquifer based on the data from March 2000. Water level measurements recorded for these wells through March 2002 indicate similar configurations of the water table and piezometric surface over time (Table 2-20).

Figure 2-5 presents a qualitative model of the relationship between the alluvial aquifer water table and the bedrock piezometric surface of groundwater flow system; a system in fractured bedrock that is subparellel to the slope gradient. The fracture-controlled groundwater communicates with, and recharges the alluvial water table, which ultimately communicates with the San Luis Rey River valley. The fractured bedrock flow system can be arbitrarily differentiated into an upper zone of flow through a network of interconnected fractures, and a deeper zone of relatively lower flow resulting from more widely spaced fractures.

Using standard contouring and hydrogeologic procedures, the available data suggest northerly groundwater flow dominated by recharge from Gregory Mountain (Figure 2-3B and Plate 2). In the upper reaches of the canyon the gradient is about 0.2 ft/ft to the north. The gradient becomes shallower toward the mouth of the canyon (about 0.1 ft/ft to the north).

Data obtained on September 13, 1999, quarterly in 2000 and monthly in 2001 indicate very little fluctuation in groundwater elevations in wells and as a result, it is concluded that the fractured-rock aquifer piezometric surface is consistent over time and is thus predictable.

Because the landfill excavation will be a minimum of five-feet above the highest anticipated groundwater piezometric surface elevation, the excavation for the landfill will not affect the direction of groundwater flow. Though the landfill is designed above the historical piezometric surface, a subdrain system will still be constructed below the landfill in the unlikely event of a higher than anticipated increase in groundwater elevation. Subdrain design in discussed in more detail in Section 3.1.1, below.

Groundwater recharge could decrease slightly once the landfill is constructed, because the liner system will effectively eliminate infiltration over the footprint area. Assuming a conservative infiltration rate of 1.6 inches per year (about 10 percent of precipitation), it is calculated that this could result in an average decrease in groundwater recharge of 2,960 ft^3/day (about 15 gpm) or 25 acre-feet per year across the site following landfill completion (GLA, 1997).

2.4 GROUNDWATER QUALITY

As described in Section 2.1 above, the project site includes existing agricultural, dairy and cattle grazing uses. Problems associated with dairy operations in the San Diego region include groundwater mineralization, the addition of nitrates to groundwater, surface runoff of biodegradable and suspended material, nuisance odors, the addition of nutrients to adjacent surface water streams and other miscellaneous problems. As a result of historical land uses on the property, agricultural irrigation return water is a major on-site influence on groundwater quality. Agricultural return water is the wastewater which runs off or leaches through an irrigated area and the two major concerns with this water are salt loading and the release of applied chemicals. Since the water supply in the San Diego region is already quite high in salts and the climate is dry, irrigation generally results in salt accumulation in soil. If these salts are not leached out by regularly applying more irrigation water than is needed for evapotranspiration, salts accumulate in the root zone and the land eventually becomes too salty for agriculture. Though saline soils can often be reclaimed by leaching, the percolation of the leach water can result in significant groundwater degradation.

Modern agriculture often relies on extensive use of applied chemicals such as fertilizers, pesticides and herbicides to obtain high crop yields. The release of applied chemicals into surface and groundwater can have adverse effects on the quality of those waters and the beneficial uses supported by them. The application of agricultural chemicals, in some cases, has been linked directly to aquatic toxicity and is suspect in many impaired water bodies. In addition to degradation of the aquatic environment, the contamination of ground and surface waters by pesticides and fertilizers is believed to also pose a threat to human health.

Hanson's sand and gravel quarry is located northeast of the project site. The largest volume of waste from sand and gravel processing operations results from product washing. Many of the sedimentary deposits mined for sand and gravel in the San Diego region contain a high percentage of silt and clay, and extensive washing is required to remove these fine materials. Other waste includes cement truck wash water, sediment separated from the wash water, and rejected product. Recycled wash waters are generally discharged to storage ponds and can contain high concentrations of TDS because of evaporation and leaching from product materials. The percolation of these recycled waters can also adversely affect groundwater quality.

2.4.1 Groundwater Monitoring Results

Initial Water Quality Sampling

In the course of performing the hydrogeologic evaluation for the site, GLA performed a limited water quality evaluation in August 1999. On-site monitoring wells, local residential/production wells and the San Luis Rey River were used to assess the current groundwater quality in the vicinity of the project site. Specifically, samples were obtained from upgradient monitoring wells GLA-4 and GLA-5 and downgradient wells GLA-2, GLA-7 and GLA-10 (Figure 2-3B). Three residential/production wells identified as Residential wells 2, 3 and 4, were also sampled within the San Luis Rey River valley (Figure 2-7). Residential well 2 is located on the west side of the project site near the Verboom residence, Residential well 3 coincides with the SLRMWD well #34, and Residential well 4 (Lucio well #2) is located on the north side of the river on the former Lucio Family Dairy property. The samples were analyzed for the indicator parameters (chloride, nitrate as nitrogen, pH, sulfate, total dissolved solids and volatile organic compounds ([VOCs] by EPA Method 8260). The results of this water quality evaluation are summarized below, and a summary of the water quality analytical data is provided in Table 2-3. Copies of the analytical reports are provided in Attachment 3.

TDS in groundwater samples collected from wells during the August 1999 sampling event ranged from 444 to 992 mg/l. Nitrate as nitrogen concentrations ranged from 0.077 mg/l to 26.2 mg/l. Only the TDS in the groundwater sample from upgradient well GLA-4 (444 mg/l) actually was below the state recommended maximum contaminant level (MCL) of 500 mg/l for drinking water and beneficial groundwater use designation (RWQCB 1994). It should be noted that water delivered by the SDCWA and its member agencies to users throughout the county has typical TDS concentrations ranging between 500 and 700 mg/l, so with respect to this parameter the groundwater resource at Gregory Canyon can be considered typical of San Diego County. Samples collected from upgradient well GLA-5 contained concentrations of nitrate as nitrogen (16.6 mg/l) and sulfate (306 mg/l); both above state recommended MCLs of 10 mg/l and 250 mg/l, respectively (although for sulfate the state provides an upper limit of 500 mg/l under the secondary MCLs). Downgradient well GLA-2 contained the highest concentrations of nitrate as nitrogen (26.2 mg/l) and also exceeded the state and federal MCLs for this constituent. Based on a review of these 1999 groundwater quality data, these results are generally consistent with those obtained from earlier water quality studies (WCC, 1995) and suggest some nitrate impacts locally, likely related to the agricultural/dairy uses of the property.

During the initial August 1999 water quality investigation, a few volatile organic compounds were detected in the water quality samples. The sample from downgradient well GLA-2 contained estimated trace concentrations (i.e., between the laboratory method detection limits and the laboratory reporting limits) of acetone (4.3 micrograms per liter [µg/l]), toluene (0.52 µg/l) and p+m-xylenes (0.69 µg/l). Acetone was also detected in samples from Residential well 4, and the upgradient surface water sample. Acetone is a common solvent used in analytical laboratories and is a likely laboratory contaminant. Toluene and the xylene isomers are commonly associated with gasoline. The measured concentrations of toluene and xylenes are well below state primary MCLs of 150 µg/l and 1750 µg/l, respectively, and although they may suggest low level gasoline impacts, they could also be the result of field- or laboratory-introduced contaminants. Finally, chloroform was measured at a concentration of 1.2 µg/l in the sample from Residential well 4. Since chloroform is used in analytical laboratories and is a common constituent in treated drinking water, it too is a suspected laboratory- or field-introduced contaminant.

Background Water Quality Sampling

In accordance with CCR 27 Section 20415(e)(6), GLA obtained four quarters of groundwater and surface water data from the proposed background monitoring points and wells downgradient of the proposed landfill site to evaluate background water quality values between December 2000 and December 2001. The sampling program included collection of samples from the bedrock aquifer in upgradient (background) wells GLA-4, GLA-5, and GLA-11, and downgradient (point-of-compliance) wells GLA-2, GLA-10, GLA-12, GLA-13, and GLA-14, and from the alluvial aquifer in background (upgradient) well Lucio #2, and downgradient alluvial wells GLA-16, and SLRMWD designated well #34. Samples collected from each of these wells were analyzed for the full suite of constituents of concern (COCs) provided in the Code of Federal Regulations (40 CFR Part 258, Appendix II). Included in this list of compounds are cyanide, sulfide, 20 metals, VOCs, semivolatile organic compounds (SVOCs), chlorinated herbicides, pesticides and polychlorinated biphenyls (PCBs). In addition, samples were submitted for indicator parameters including chloride, nitrate, sulfate, pH, and TDS. Summaries of the analytical results obtained for each groundwater monitoring well are provided on Tables 2-4 through 2-14 and Tables 2-15 and 2-16 present a comparison of the median concentrations of inorganic constituents in groundwater obtained from August 1999 (if available) and the subsequent four sampling rounds. These tables also present the detected organic compounds (averaged when a constituent was detected more than one time) for bedrock aquifer and alluvial aquifer samples, respectively. Copies of the analytical reports are provided in Attachment 3.

In evaluating general water quality, the median values for each constituent were compared with currently established state and federal MCLs and San Diego RWQCB Basin Objectives. Review of the median data indicates similar water quality to the data obtained earlier with concentrations of chloride, TDS and nitrate in some bedrock wells above the upper state MCL, while water quality in the alluvial wells was found to meet state and federal MCLs and the local basin objectives. The following table presents those median concentrations that were found to equal or exceed a currently established state or federal MCL or basin objective.

Bedrock Aquifer Well Exceedances
MCL versus Median Concentration

CONSTITUENT	STANDARD	UPGRADIENT LOCATIONS			DOWNGRADIENT LOCATIONS				
General Chemistry (mg/L):		GLA-4	GLA-5	GLA-11	GLA-2	GLA-10	GLA-12	GLA-13	GLA-14
Chloride	300$^{(4)}$ / 500$^{(1,3)}$	NA	NA	NA	450	NA	NA	NA	NA
Nitrate	15$^{(4)}$ / 45$^{(1,3)}$	NA	18.8	NA	42.9	NA	NA	28.3	15.3
Total Dissolved Solids	900$^{(4)}$ / 1000$^{(2)}$	NA	1120	NA	1410	NA	NA	1000	NA

NOTES: 1. California Primary Drinking Water Standards.
2. California Secondary Drinking Water Standards – Upper Limit.
3. Federal Maximum Contaminant Levels.
4. Basin Objective – Pala Hydrologic Subarea.
NA – Not Applicable (No exceedance).

In the bedrock aquifer, comparison of the median data across the site indicates that samples from upgradient (background) wells GLA-4 and GLA-11 contained some of the lowest concentrations of most of the general chemistry constituents and several metals. Samples from downgradient well GLA-2 contained several general chemistry and metals at the highest concentrations in the bedrock aquifer wells. The samples from background well GLA-5, located at the head of the canyon, contained elevated concentrations of nitrate and TDS, and the highest concentrations of sulfate and barium compared with the other bedrock aquifer wells. For the alluvial aquifer, the groundwater data is relatively consistent between the three sampled wells, with slightly lower concentrations measured in SLRMWD well #34.

Review of COC data demonstrates that no pesticides or PCBs were detected in groundwater at the Gregory Canyon site, and only one chlorinated herbicide (2,4-D) was identified once and at a trace concentration in the sample from downgradient bedrock well GLA-13. In contrast, several VOCs and SVOCs were detected one or more times in the proposed groundwater monitoring system samples. The majority of the detected VOCs are either common laboratory compounds such as acetone, carbon disulfide, and chloroform, or are constituents in hydrocarbon-based fuel (such as benzene, toluene, ethylbenzene and xylenes). Review of the quality assurance/quality control (QA/QC) blank sample data obtained with the primary samples also indicates measurable VOCs in blank samples including benzene, ethylbenzene, toluene and xylenes in the equipment and field blanks. The majority of the detected SVOCs were phthalates, which are plasticizers commonly attributed to laboratory or field contamination. Because the data obtained to date suggest only sporadic detections of VOCs and SVOCs, those identified are often attributed to laboratory/field-introduced impacts, and there are few on-site sources for these compounds, laboratory or field contamination is suspected. This conclusion will be confirmed during future quarterly sampling events (scheduled to begin following construction and testing of the groundwater monitoring network to be completed in the spring 2004) to obtain a representative database (approximately 16 data points) of background water quality data prior to and during development of the landfill. The monitoring program will include collection of samples from existing bedrock monitoring wells GLA-2, GLA-4, GLA-5, GLA-11, GLA–12, GLA-13, GLA-14, and GWM-1 (also added for additional point of compliance coverage), additional proposed monitoring wells scheduled to be constructed in the spring 2004 (e.g., GLA-A, GLA-B, GLA-C, GLA-D, GLA-3S and GLA-17); existing alluvial well GMW-3, and to be constructed replacement alluvial wells Lucio #2R and SLRMWD#34R; and the surface water sampling points that contain sufficient water. The samples will be tested for the 40 CFR 258 Appendix I list of constituents, excluding metals but including the metal surrogates, calcium, magnesium and sodium. Because the site is located in an agricultural land use area, the samples will also be tested for chlorinated herbicides and pesticides. A discussion of this program is also provided in the Monitoring and Reporting Plan developed specifically for the Gregory Canyon Landfill.

2.4.2 Surface Water Monitoring Results

In addition to groundwater samples, surface water samples were collected in the San Luis Rey River from surface water stations SLRSW-1 (upstream of Gregory Canyon) and SLRSW-2 (downstream of Gregory Canyon). The samples were also analyzed for the full suite of COCs listed within 40 CFR 258, Appendix II, along with the metal surrogates chloride, nitrate, sulfate, pH, and TDS. Summaries of the analytical results obtained for each surface water monitoring station are provided on Tables 2-17 and 2-18. Table 2-19 presents a comparison of the median surface water sample concentrations obtained from August 1999 and four sampling rounds for inorganic constituents and presents the detected organic compounds (averaged when a constituent was detected more than one time). Copies of the analytical reports are provided in Attachment 3.

Comparison of the surface water sample data with currently established state and federal MCLs and surface water basin objectives indicates that only the median TDS concentrations in both surface water samples exceeded the basin objective. Further review of the data indicated very little difference between the median values up and downstream of the canyon. This finding is not surprising considering the relatively undisturbed nature of the area.

2.4.3 Analysis of Potential Impairment to Groundwater

The alluvial valley that forms the Pala groundwater basin has an average width of 2,600 feet and a maximum depth of about 240 feet (average thickness of 150 feet). The groundwater gradient in the basin is approximately 0.004 feet/feet (horizontal displacement of 400 feet to one vertical foot), which is similar to the topographic gradient of the ground surface. Depths to water were estimated to range from less than five feet to approximately 10 feet below ground surface. The average hydraulic conductivity of the alluvial sediments was estimated to be about 80 to 100 feet/day, with higher conductivity materials in the main river channel and lower conductivity materials (8 feet/day) skirting the edges of the valley (Geraghty & Miller, 1988).

The proposed landfill will occupy one of the tributary canyons to the Pala groundwater basin. The western part of the basin is managed by the SLRMWD, which in 1995 requested an assessment of potential impacts of a leachate release from the proposed landfill on the basin. At the request of the SLRMWD, computer model simulations of groundwater flow in the Pala Basin in the vicinity of the proposed landfill were performed and a simulation of the expected groundwater flowpath from the landfill was presented (GLA, 1995). Estimated worst-case leakage from the landfill was modeled as was its affect on identified production wells within the basin. The analysis assumed that the leachate containment systems incorporated in the project design meet the minimum requirements for environmental protection mandated by U.S. and California EPAs.

Using Pala Basin hydrogeologic characterization summary input data, a two-dimensional groundwater flow model was developed using the finite difference computer program Flowpath (Franz and Guiguer, 1992). Constituent transport modeling with the Flowpath computer program is accomplished with the use of particle tracking techniques, which simulate constituents as "particles" that follow the groundwater flowlines. Two conditions were simulated. The first simulated groundwater flow under existing conditions with a worst case leakage through the liner of about 10 gallons per day per acre (1,850 gallons per day for the 185-acre refuse disposal area of the landfill [excluding the transmission pads]) and head conditions in the Pala basin at levels approximately equal to those shown on the Geoscience (1993) hydrogeologic base map. The release is assumed to be a point source and is modeled as an injection well. The second simulation involved a lower groundwater elevation (i.e., a starved basin) approximately 20 feet below ground surface in the southwest corner of the basin, as could happen if increased pumping took place during extended drought periods.

The first model showed that steady-state groundwater flow in the Pala basin can be reasonably assumed to follow the topography, with flow lines following the general trend of the river (Figure 2-6A). Owing to slightly increased recharge in the vicinity of the river, groundwater velocities are slightly higher immediately adjacent to the trace of the river. Figure 2-6A also shows the predicted pathways of particles potentially released from the landfill. As shown, the particle pathways could extend past wells #41 and #42, and at least 2/3 of a mile from the downgradient boundary of the project property, if the release is allowed to continue under steady state conditions. It should be noted that both of these wells are still within the footprint of the property owned by Gregory Canyon Ltd. On a transient simulation, the particles would need approximately 5.5 years to travel the distance of 2,000 feet between the toe of the landfill and wells #41 and #42, at an average flow velocity of approximately one foot per day. From this point, the particle pathways extend along the southern perimeter of the canyon until the particles intercept a point of constriction within the canyon at the base of the bluff where the Verboom homestead is located. At this point the pathway merges with the underflow of the San Luis Rey River, which would conceivably then carry the particles farther downstream, if no source control were introduced.

Figure 2-6B illustrates the second groundwater flow simulation for the case where groundwater head levels have been reduced by 10 feet in the southwest part of the basin to a level approximately 20 feet below ground surface. As a result of the reduced groundwater head levels in the downgradient part of the model, a steeper groundwater gradient is induced, and slightly higher groundwater flow velocities result. Though there is a resulting change in groundwater flow velocity, the change in the trajectories of particles is very small, as demonstrated by the almost identical particle tracks calculated for the second simulation (Figure 2-6B). Under these conditions, the particles would need approximately 4.9 years to travel the 2,000 feet between the toe of the landfill and wells #41 and #42, at an average flow velocity of approximately 1.1 feet per day. This flow path scenario provides a basis for the location of monitoring wells as part of the detection monitoring program for the Gregory Canyon Landfill.

2.5 ADDITIONAL HYDROGEOLOGIC REFERENCES

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